A Focus on Streaming Instability as a Probable Cause of Dispersion in the Sheet Plasma Negative Ion Source

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INTRODUCTION

It is observed in the operation of the Sheet Plasma Negative Ion Source (SPNIS), that the sheet configuration of the plasma cannot be maintained at pressures above a certain limit. For instance hydrogen plasma disperses and shows spatial inhomogeneity at pressures above 0.05 Torr, while at pressures higher than 0.01 Torr the same occurs for argon plasma. The cause of the dispersion is not understood, as yet. This paper is the first of a series of attempts to find the root of the dispersing phenomenon. Focus was done on **Streaming Instability** as a probable cause.

THEORY

When charged particles in a plasma are driven by an electric field, different species have drifts relative to one another. The drift energy creates streaming instability manifested in the form of self excited waves. This type of instability is characteristic of body-wave perturbations. The interaction between waves and particles lead to the temporal growth of unstable oscillations.

To extract stability information, dispersion relation of waves suspected to exist in the system is utilized. The wave equation is derived using Poisson's relation, equations of motion and mass continuity for each species. First order approximations are employed; terms containing higher powers of amplitude factors are neglected and effects like particle pressures, gravity, like species interaction are not taken into account. The dispersion relation is found to be

$$1 = \frac{4\pi n e^2}{m}\left[\frac{\frac{m}{M}}{\omega^2} + \frac{1}{(\omega - kV)^2}\right]$$

M, m, n, e and V are the ion and electron mass, electron density, charge and drift velocity respectively; k denotes wave number. This is a quartic equation in ω. If all the roots are real, each would indicate ordinary oscillations, while complex roots - unstable oscillations. The latter always occur in conjugate pairs, negative Im(ω) points to a damped wave which swiftly dies out. A positive Im(ω) however indicates an exponentially growing wave, a rapidly increasing function with respect to time corresponding to an unstable mode (Goldston & Rutherford, 1995). This is an indication of an unstable plasma; the system will seek out a state of lower potential energy because an instability is a motion which decreases any available free energy and brings the plasma closer to thermodynamic equilibrium (Chen, 1990). This instability produces spatial inhomogeneties in which plasma particles of the same species become "bunched" together ultimately causing the energy of the particles to be significantly dissipated into perturbing waves. Such being the case, plasma confinement can be compromised. As stated earlier, these growing waves probably cause the dispersion of the sheet configuration.

EXPERIMENTAL SET UP AND METHODOLOGY

The test facility is shown in Fig. 1. The setup is discussed by Ramos (1990) and Abate (2000). The base pressure is at 2 x 10^{-5} Torr. Filament, plasma and

Helmholtz currents are set at 20A, 4A, and 10A respectively. Argon gas is fed into the production chamber at pressures 0.01 and 0.015 Torr. The pressure at which a sheet configuration can be maintained is at 0.01 Torr while at 0.015, plasma starts to disperse. It is no longer sheet in form but becomes more visibly diffused. A Langmuir probe that can be moved in the transverse direction is used to obtain plasma parameters needed in this experiment. The probe is moved outward starting from the center, at 0.5 cm increments. This is done at 8 locations (including the center), with a sweep of the probe's voltage biasing from +30V to –30V per location. It is interfaced into an Intel-based computer through the general programmable interface bus protocol to simplify and speed up data acquisition. Imposing the condition that the distribution is Maxwellian in character, which is normally allowed for first order approximations, we obtain the most probable velocity of the bulk of the electrons via $V=(2KT_e/m)^{1/2}$ (Arzimovich, 1965). All experimental parameters gathered are then used to solve for the roots of the dispersion relation to determine the existence of streaming instability.

RESULTS AND DISCUSSION

Figs. 2 to 7 show electron temperatures, densities and velocities as a function of probe distance for both sheet and dispersed plasma configurations. Temperature and velocity plots show that energetic electrons are found near the center of the plasma while cold electrons are found in the periphery. It is observed though, that the electron energy is higher for the sheet configuration than the dispersed state. However, calculations using the Spitzer relation show that the dispersed state has a higher resistivity and is closer to thermal equilibrium as noted in its relatively lower gradient. The imposed condition that the distribution is Maxwellian is valid as shown by the 'bell-shaped' profile of the electron densities.

When all obtained values of V are substituted into the dispersion relation, the results yield purely real roots. This is true for all locations of the probe in both the sheet and dispersed states, indicating the absence of exponentially growing waves. Streaming instability does not exist in the system.

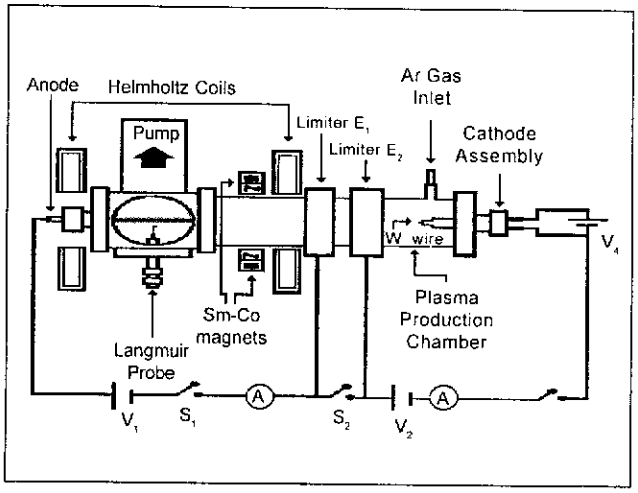

Fig. 1. Schematic diagram of the Sheet Plasma Negative Ion Source

CONCLUSION

It is observed that as we move in the transverse direction away from the center of the sheet plasma, electron densities, temperatures and velocities decrease exponentially as expected for a Maxwellian distribution.

We have verified experimentally that there is no streaming instability in the plasma generated by the SPNIS. This is confirmed by the fact that the roots of the dispersion relation for all data points are real. Therefore, as to the theory that the observed plasma dispersion is caused by streaming instability, our results explicitly negates the idea; self excited waves due to this particular instability do not exist in the system. Other different mechanisms are responsible for the dispersion. One probable cause we are currently investigating is the **Resistive Tearing Instability.** A marked increase in the resistivity of the dispersed plasma is observed. The increase can be a destabilizing factor since it creates an unstable mode which tears the confining magnetic field (Rosenbluth, 1963). Results of this investigation will be shown in succeeding papers.

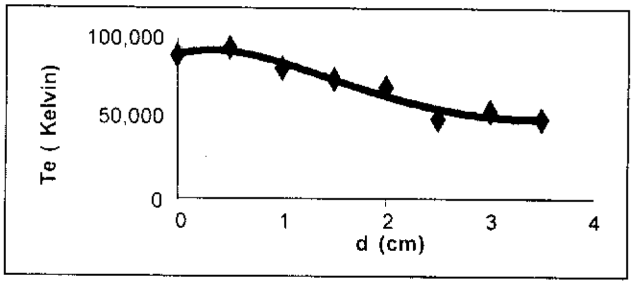

Fig. 2. Electron temperature vs. probe distance for sheet plasma

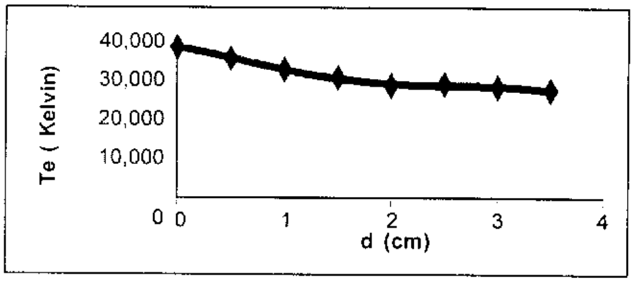

Fig. 3. Electron temperature vs. probe distance for dispersed plasma

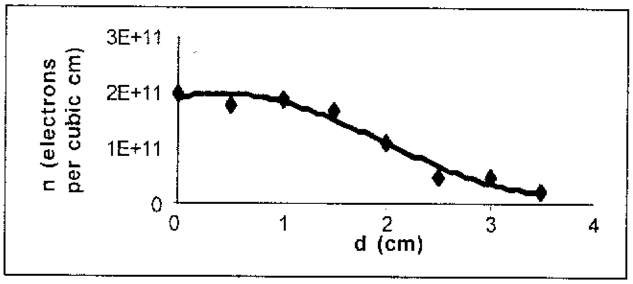

Fig. 4. Electron density versus probe distance for sheet plasma

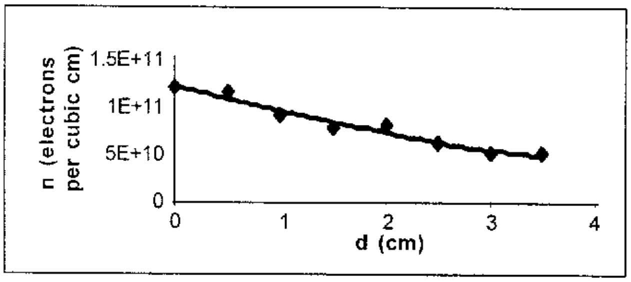

Fig. 5. Electron density versus probe distance for dispersed plasma

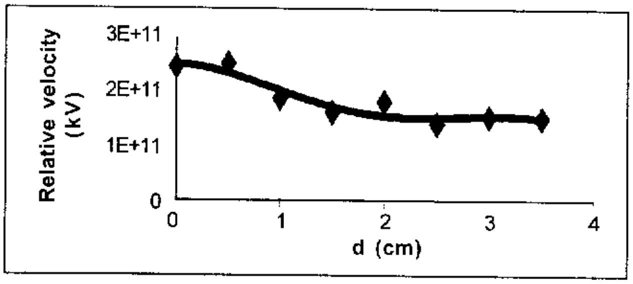

Fig. 6. Electron velocity versus probe distance for sheet plasma

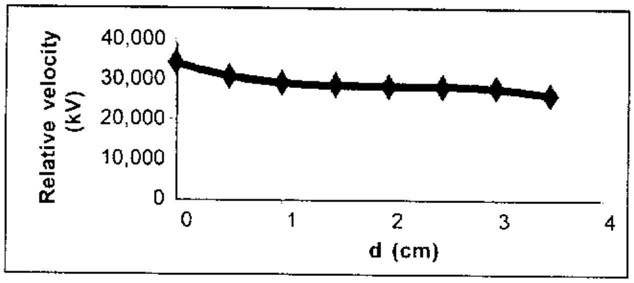

Fig. 7.Electron velocity versus probe distance for dispersed plasma

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